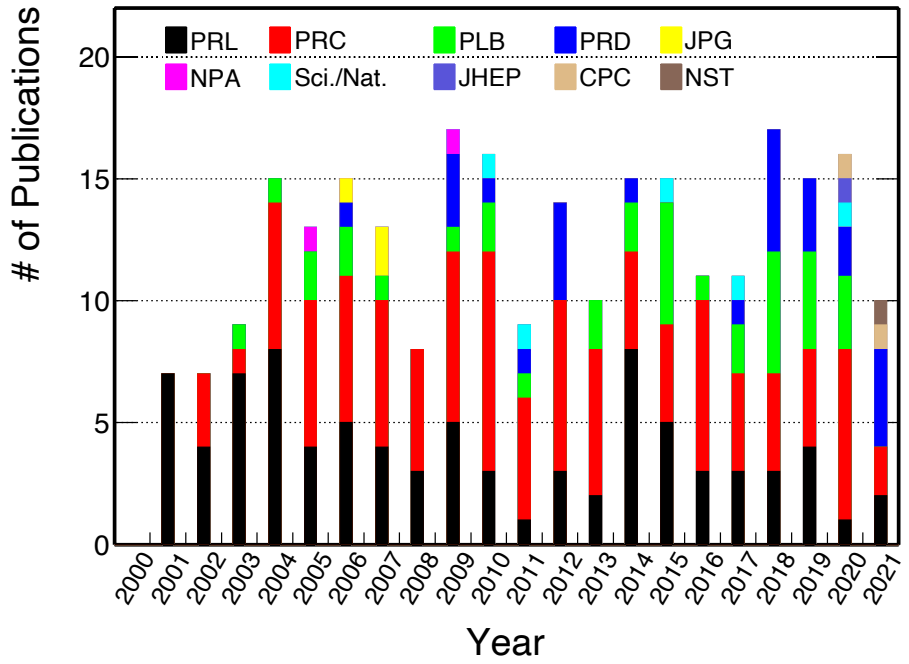
Results from the STAR HI program and the status of the BES-II

Early morning drive to shift in an eerily quiet BNL

Helen Caines - Yale - on behalf of the STAR Collaboration

Continued strong engagement



>85% (223/261) now on HEPData

Many new results published and presented at conferences in 2020 and 2021

2020: 16 published (1 PRL, 7 PRC, 3 PLB, 2 PRD, 1 Nature Physics, 1 JHEP, 1 CPC)

2021: 10 published (2 PRL, 2 PRC, 4 PRD, 1 NST, 1 CPC)

Under Journal review: 8

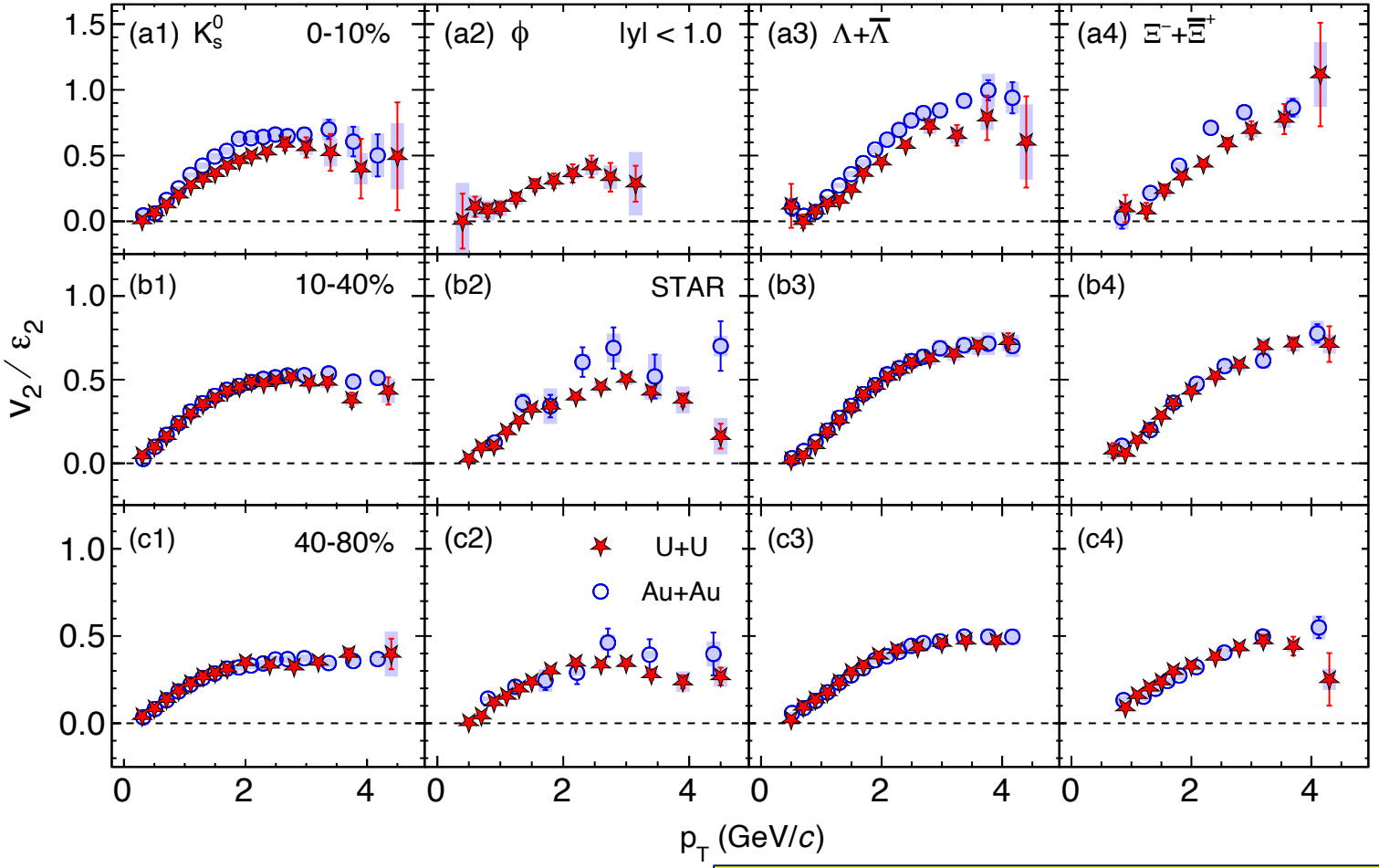
Active GPCs: 37 (in collaboration review: 8)

AUM Thesis Winner: Dr. Rafal Sikora AGH University of Science & Technology
Renate W. Chasman Award: Maria Stefaniak WUT/ Subatech-IMT Atlantique

Two new institutions joined collaboration: Ramkrishna Mission Residency College, India (**Amal Sarkar**), University of Calabria & INFN-Cosenza (**Salvatore Fazio**)

Effects of Uranium deformation on flow

Published on Wed



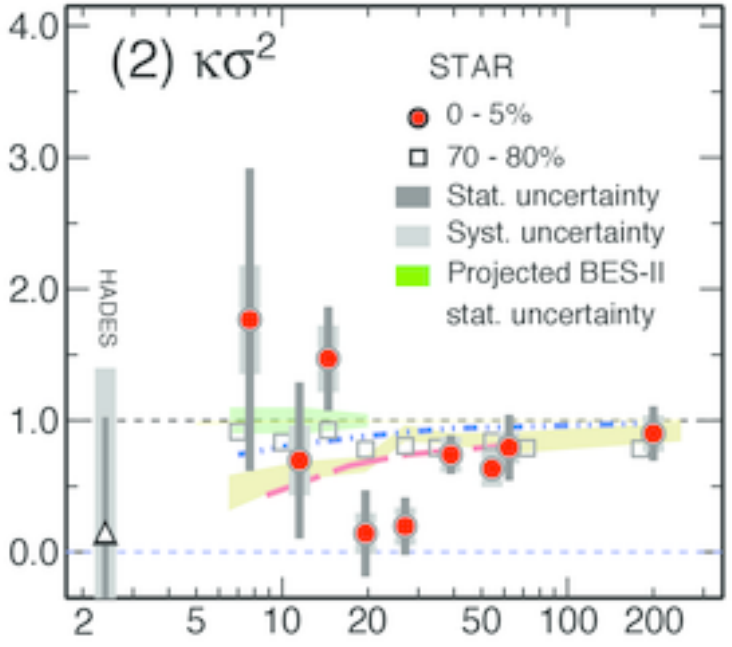
In central events: v_2(U+U)<v_2(Au+Au)

ε_2(U)/ε_2(Au) ~ 1.5

Dynamics beyond eccentricity affect flow in highly deformed Uranium

Phys. Rev. C **103** (2021) 64907

Hints of critical fluctuations



First measurement of net-proton C_6/C_2 at RHIC

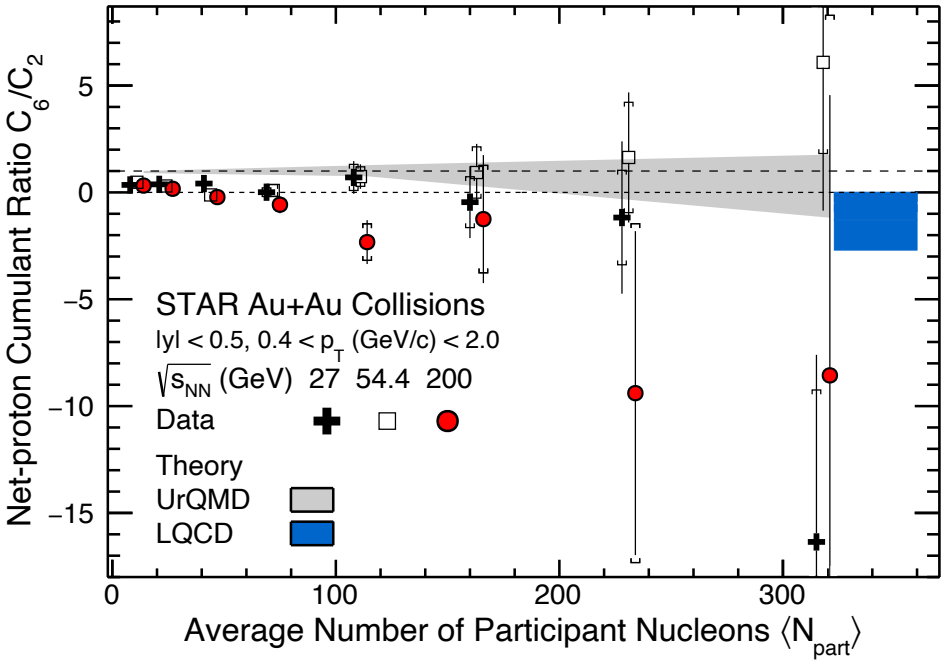
27 & 54.5: Consistent with zero

200: Negative in more peripheral collisions

κ/σ^2

BES-I result published in PRL

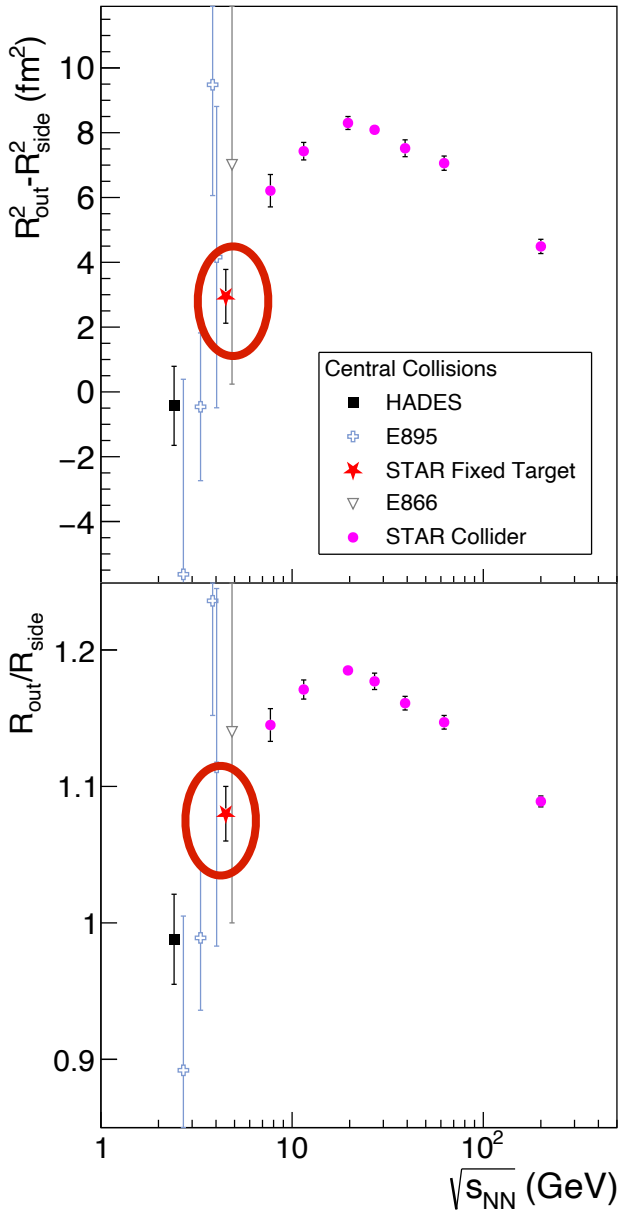
Long paper also submitted



Suggestive of smooth cross-over at top RHIC energies

Phys. Rev. Lett. **126** (2021) 92301
arXiv:2101.12413
arXiv:2105.14698

Evolution through phase transition?



Publication of first FXT data - 4.5 GeV

STAR data in combination with HADES results reveal long-sought peak in R_{out}/R_{side} beam energy dependence

- Peak predicted if system evolves through 1st order phase transition

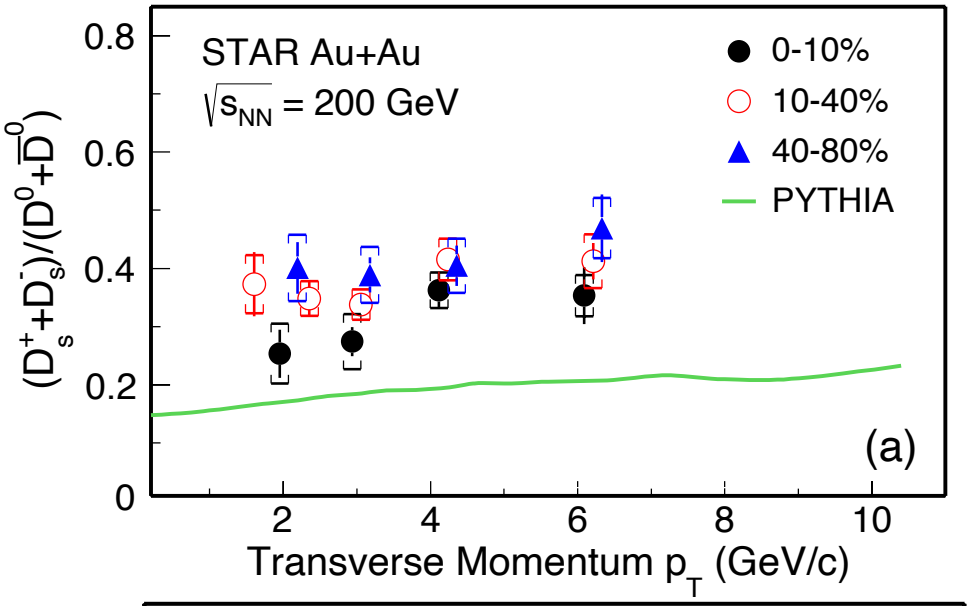
The magnitude and width of structure may allow an estimate of latent heat of QCD deconfinement transition

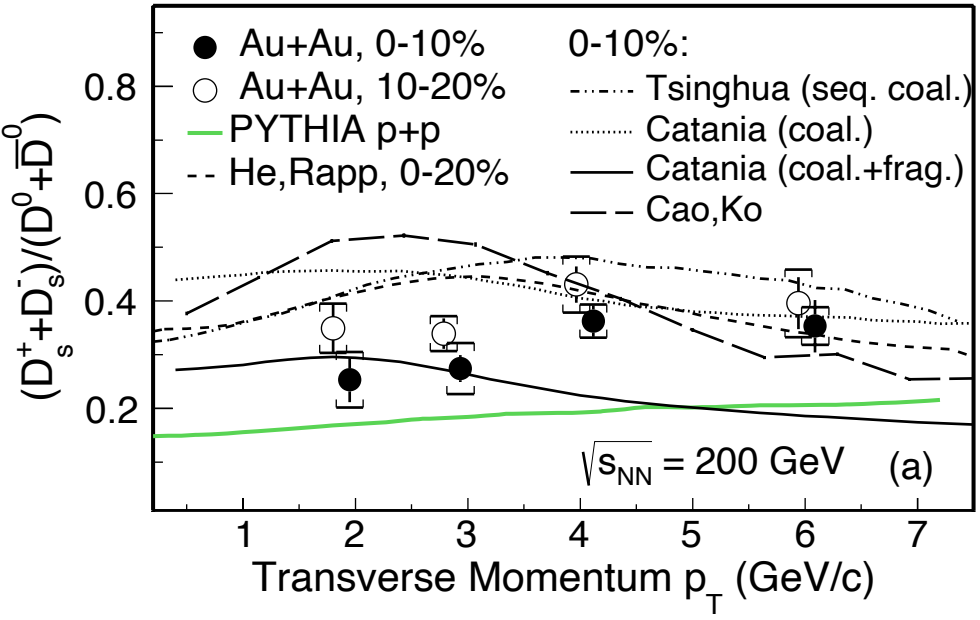
- more theory input needed

First measurements of pion directed and elliptic flow also presented

Phys. Rev. C **103** (2021) 34908

Strange-charm coalescence





Continuing to publish HFT data

$D^{\pm}_s/D^0$(Au+Au) > $D^{\pm}_s/D^0$(PYTHIA)

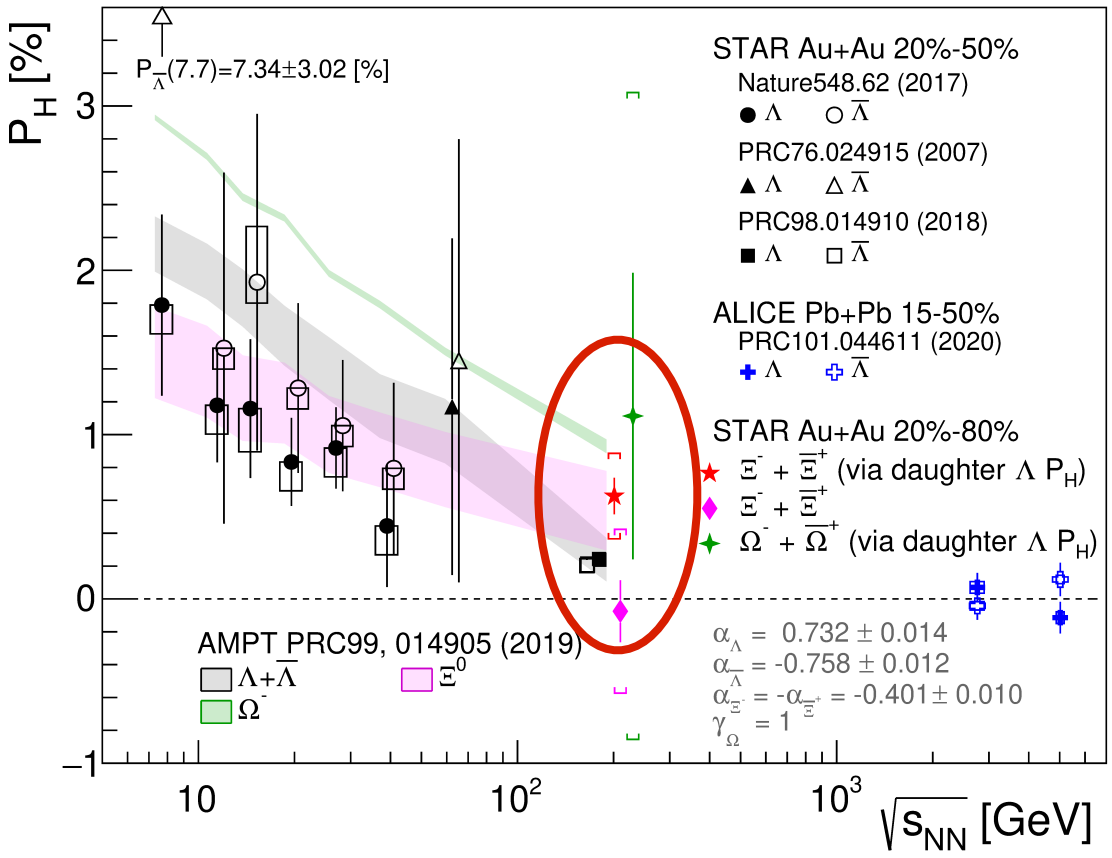
p_T integrated ratio consistent with statistical hadronization model fit to strange and light hadron yields

Models incorporating coalescence perform better but p_T dependence still not well described

Coalescence of charm with strange quarks in the QGP

arXiv:2101.11793

Vorticity of multi-strange hadrons



First measurement of global polarization of Ξ and Ω

Results qualitatively captured by AMPT

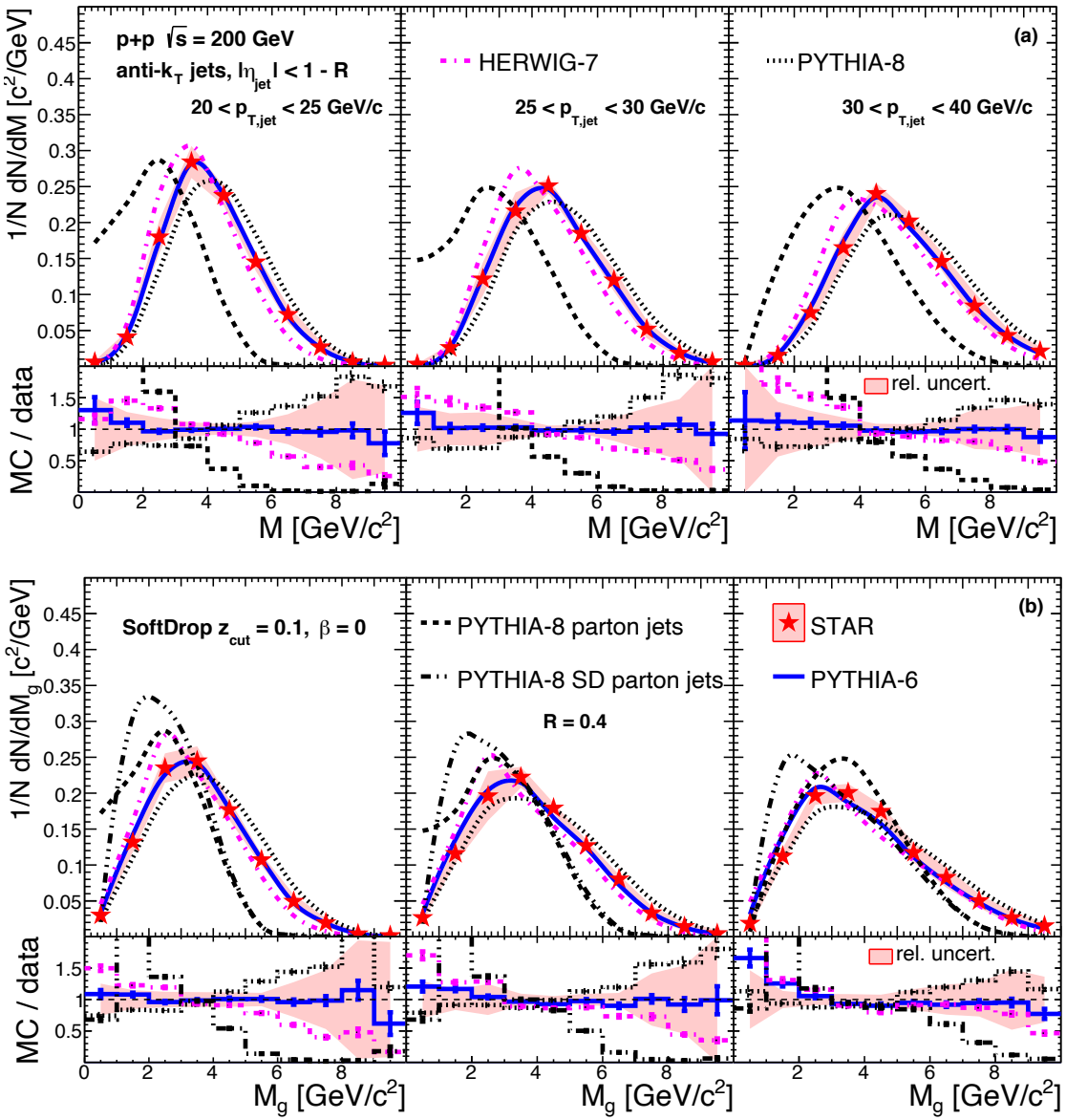
Ξ centrality trends consistent with expectations of vorticity dependence on impact parameter

- $\langle P_\Lambda \rangle$ (%) = 0.24 ± 0.03(stat) ± 0.03(syst)
- $\langle P_{\bar{\Xi}} \rangle$ (%) = 0.47 ± 0.10(stat) ± 0.23(syst)
- $\langle P_\Omega \rangle$ (%) = 1.11 ± 0.87(stat) ± 1.97(syst)

Results reinforce picture of system fluid vorticity

Phys. Rev. Lett. **126** (2021) 162301

Jet mass: non-perturbative contributions



First inclusive fully corrected measurements

Jet mass increases and broadens with p_T
- increased phase space

PYTHIA-6 - reproduces data,
PYTHIA-8 - too high
HERWIG-7 - too low

SD-groomed mass closer to partonic mass

Wide-angle non-perturbative radiation contributions are suppressed

arXiv:2103.13286

Update on the isobar analyses

Mock data challenge
Test data structure
(27 GeV files)

Isobar-Mixed Analysis
QA, physics & code freezing
(One run is Ru+Zr)

Isobar-Blind Analysis
Run-by-run QA, full analysis
(One run is Ru/Zr)

Isobar-Unblind Analysis
Full analysis
(Ru and Zr separated)

STAR, arXiv:1911.00596
Cartoon: arXiv:2009.01230

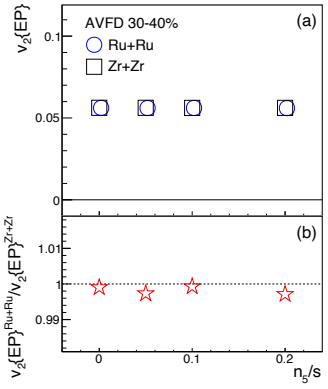
Processing...

Analyses with frozen data underway
expect to take at least 2 months

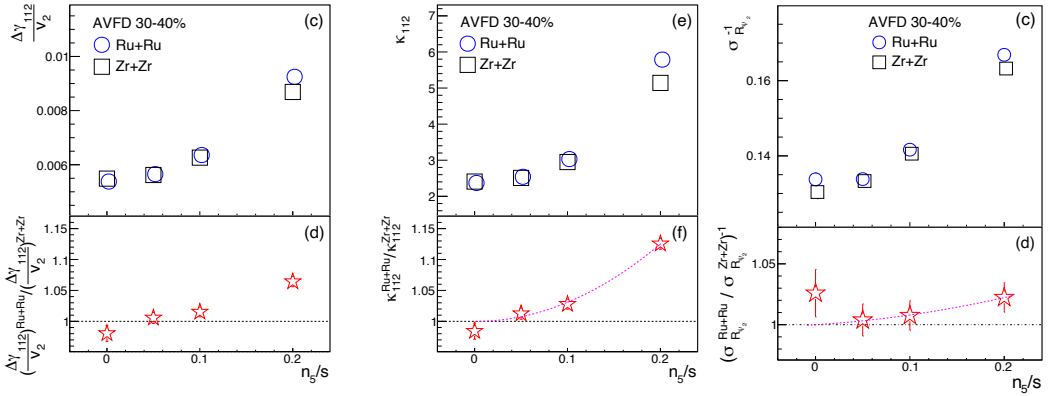
Members of CME group tested frozen code sensitivities with e-b-e AVFD
–n5/s indicates CME signal strength

Same sensitivity (inclusive Δγ, R_2) when put on same footing

Background



Examples of blind analyses variables



- note not real data

Priorities as run started

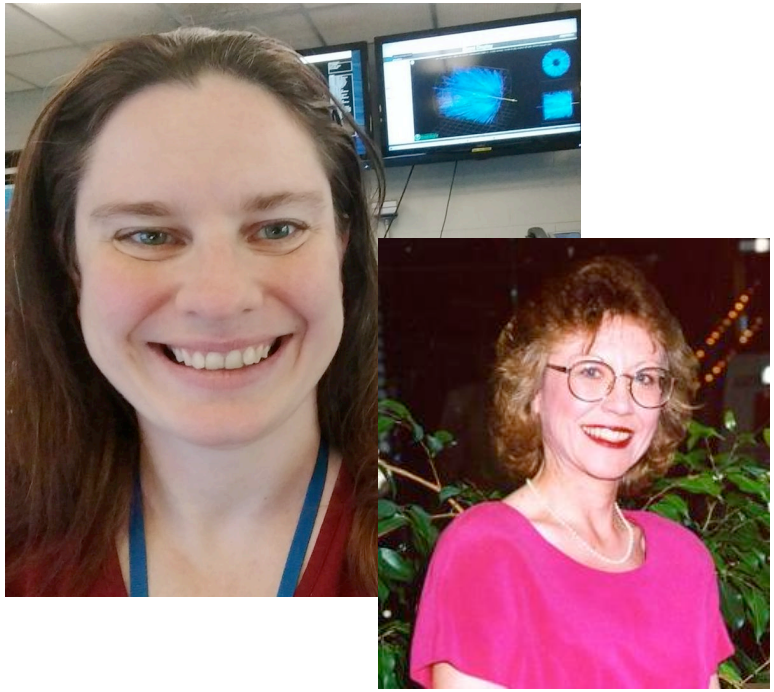
Run-21:

Single-Beam Energy (GeV/nucleon)	$\sqrt{s_{\rm NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority
3.85	7.7	11-20 weeks	Au+Au	100 M	1
3.85	3 (FXT)	3 days	Au+Au	300 M	2
44.5	9.2 (FXT)	0.5 days	Au+Au	50 M	2
70	11.5 (FXT)	0.5 days	Au+Au	50 M	2
100	13.7 (FXT)	0.5 days	Au+Au	50 M	2
100	200	1 week	O+O	400 M 200 M (central)	3
8.35	17.1	2.5 weeks	Au+Au	250 M	3
3.85	3 (FXT)	3 weeks	Au+Au	2 B	3

STAR's highest priorities was the **completion of the BES-II**

As you well know the pandemic hit

Run-21 undertaken with similar restrictions as Run-20b



Were even able to squeeze in giving a tour of STAR and sPHENIX during SQM

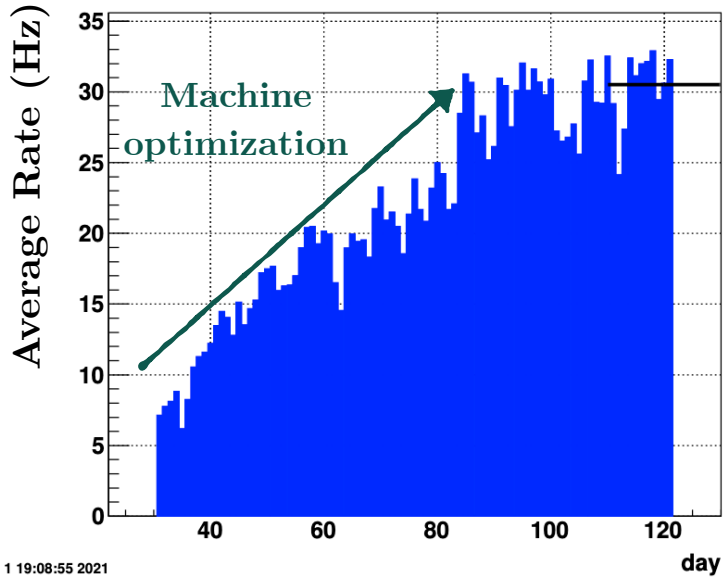
- Onsite shift persons reduced from four to two: Shift leader and detector operator;
- Period coordinator and one shift crew now remote
- Onsite cleaning per shift and minimal face-to-face interaction
- Continuous onsite Zoom feed for remote operations crews
- All opts. meetings online and open to STAR collaboration

Remote crew members took tasks very seriously despite being at home

Special thanks to Rosi Reed and Liz Mogavero - tons of work getting shifts filled and everyone on site

7.7 GeV running

BUR assumed 19-24 Hz

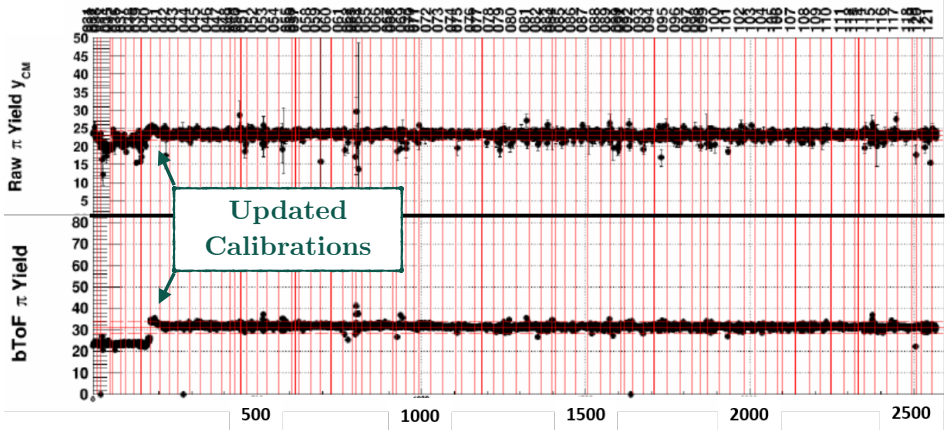


Technically challenging - beam quality deteriorates at low energies Improved with LEReC

Steady improvement over first few weeks

Fill length	Average Running Time	Average Rate	# Good Events Per Day
20-25 min	12.5 hrs/day	22 Hz (Entire run) 31 Hz (Final week)	1.4 M (final week)

Exceeded estimates by end of run



7.7 GeV run finished in 12.9 weeks (May 1)! (BUR estimate 11-20 weeks)

Weekly QA indicates data very good

FXT and 17.3 GeV running

$\sqrt{s_{NN}}$ = 3 GeV:

Smooth running with ~1.6 kHz good event rate with low backgrounds

300 M good event goal reached in < 4 days w/ 12 hrs. for APEX (BUR: 3 days)

$\sqrt{s_{NN}}$ = 9.2/11.5/13.7 GeV:

Smooth running with ~1.6 kHz good event rate with low backgrounds for higher energy FXT runs

50 M good events/$\sqrt{s_{NN}}$ goal reached in ~0.5 day/$\sqrt{s_{NN}}$ (BUR: 0.5 days/$\sqrt{s_{NN}}$)

- Comparable downtime in between runs;
- RHIC tuning for new single beam energies for $\sqrt{s_{NN}}$ = 9.2,11.5

$\sqrt{s_{NN}}$ = 17.3 GeV:

Very consistent fills with minimal downtime and low backgrounds; Average good event rate 450 Hz in latter half of run (improved with machine tuning w.r.t. first few days)

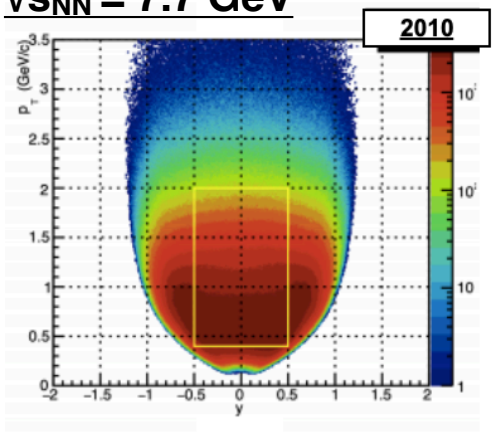
256 M goal reached in 2 weeks (BUR: 2.5 weeks)

Very efficient data taking, BUR estimates spot on

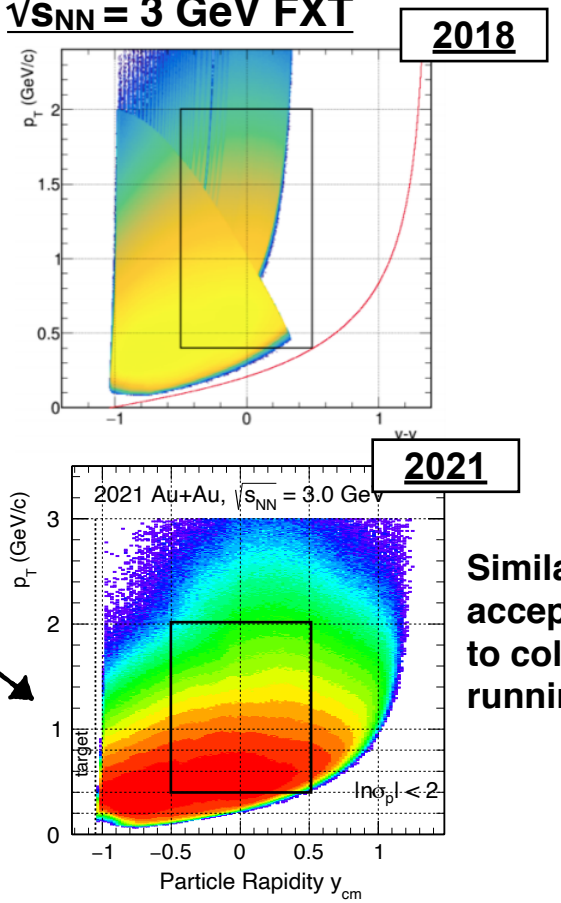
Proton acceptance comparisons

Improved acceptance from iTPC!

$\sqrt{s_{NN}}$ = 7.7 GeV



$\sqrt{s_{NN}}$ = 3 GeV FXT



Essential for proton fluctuations analyses

Similar acceptance to collider running

Real data!

O+O 200 GeV running

Long fills+low backgrounds,

Average good event rate ~1.6(0.72) kHz for min. bias (central) triggers

Minbias collected 402+125M (BUR:400 M). 125M with flipped field

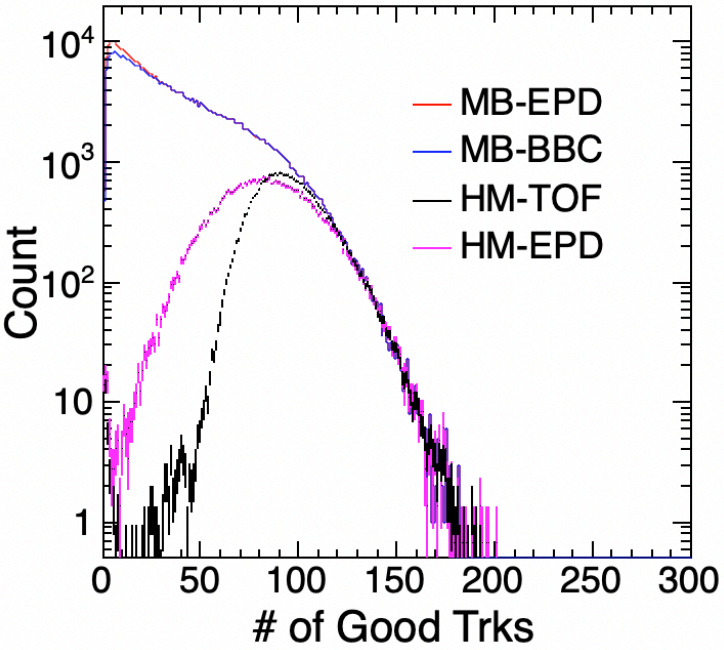
Central collected 212 M (BUR: 200M)

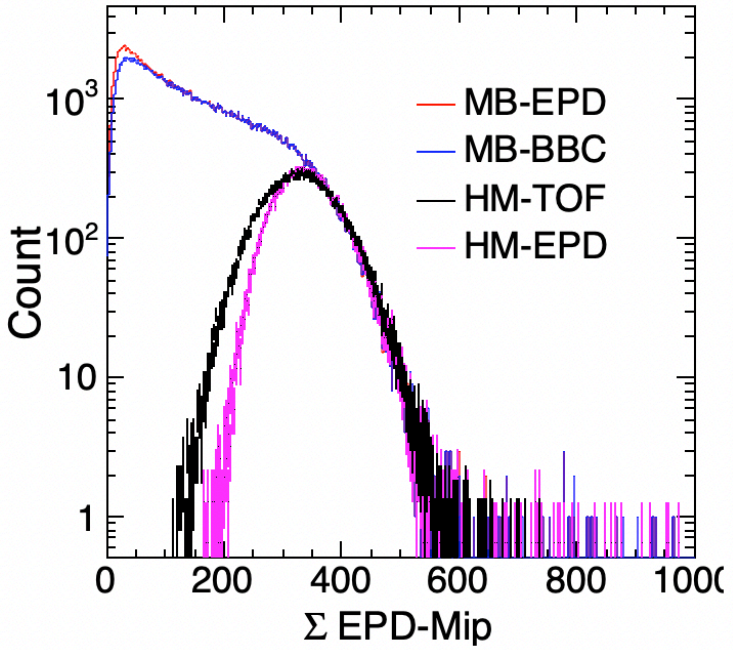
Central triggers from high multiplicity in

EPD or TPC/ToF

×5(EPC)

×10(TPC)] boost



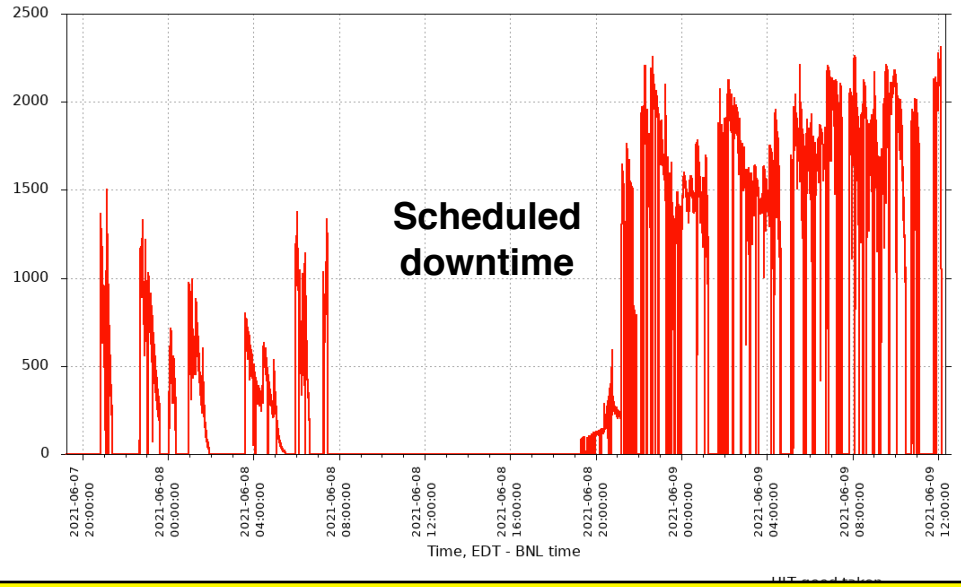


Field flip will give excellent insight into systematics

FXT at 3 GeV, high stats running

$\sqrt{s_{NN}}$ = 3 GeV restarted June 7

Predict to collect 1.7 B good event goal after 3 calendar weeks (BUR: 2 B = 1.7B+300M)



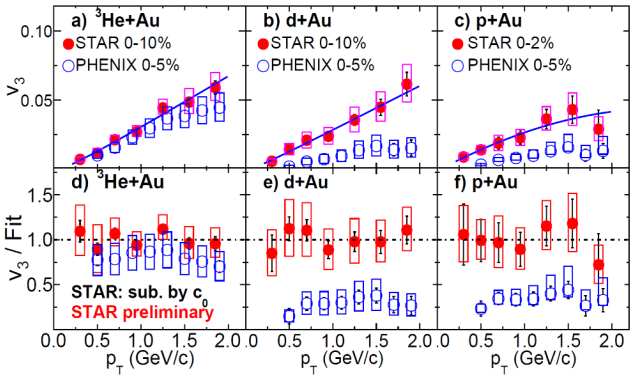
~1.3 B good events have been collected as of Mon morning

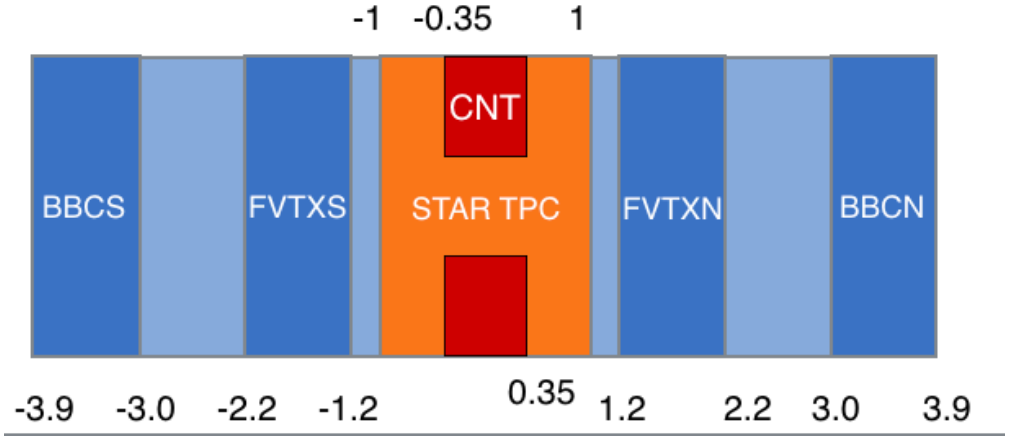
~400 M events left to collected (~52 Hrs of data collection time)

Time for one more run!?

d+Au at 200 GeV

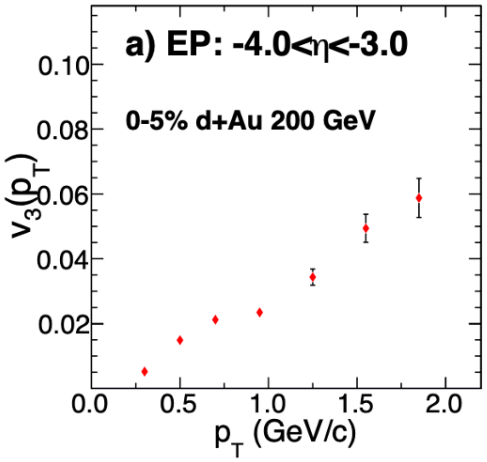
EPD (2.2<|η|<5.2) - event plane
iTPC (|η|<1.5) - flow measurement

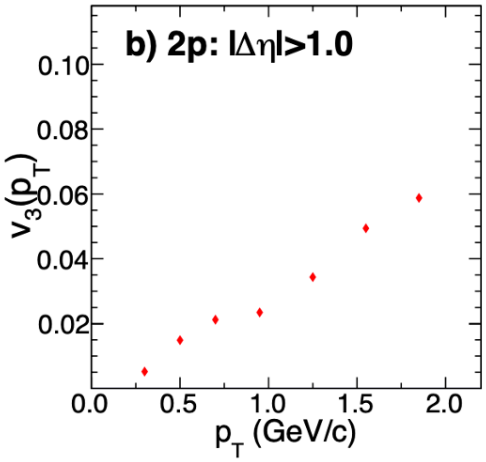




30 DAQ hours of running
100 M minimum-bias (MB)
100 M high-multiplicity (0-10% HM)

BBC rate: 10 KHz





Reduce statistical uncertainty by x8 for 2-particle correlation method

Summary

Collaboration remains energetic with publications from all PWG

New faculty positions for STAR members

Very successful run while adopting a safe covid-era shift paradigm

Consistent and excellent RHIC performance

Single-Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority	Date Completed
✓ 3.85	7.7	11-20 weeks	Au+Au	100 M	1	← May 1
✓ 3.85	3 (FXT)	3 days	Au+Au	300 M	2	← May 5
✓ 44.5	9.2 (FXT)	0.5 days	Au+Au	50 M	2	← May 6
✓ 70	11.5 (FXT)	0.5 days	Au+Au	50 M	2	← May 7
✓ 100	13.7 (FXT)	0.5 days	Au+Au	50 M	2	← May 8
✓ 100	200	1 week	O+O	400 M (+100 M FF) 200 M (central)	3	← May 24
✓ 8.65	17 3	2.5 weeks	Au+Au	250 M	3	← June 7
Ongoing 3.85	3 (FXT)	3 weeks	Au+Au	2 B	3	

From 2020 BUR:

Priority 1 program: Completed May 1

Priority 2 programs: Completed May 8

Priority 3 programs: 2/3 complete, project to finish last program by June 28

Thanks for everyone who contributed to this run

BACK UP

Event statistics requirements: FXT

Table 8: Event statistics (in millions) needed in the fixed-target part of the BES-II program for various observables.

$\sqrt{s_{NN}}$ (GeV)	3.0	3.2	3.5	3.9	4.5	5.2	6.2	7.7
Single Beam Energy (GeV)	3.85	4.55	5.75	7.3	9.8	13.5	19.5	31.2
μ_B (MeV)	721	699	666	633	589	541	487	420
Rapidity y_{CM}	1.06	1.13	1.25	1.37	1.52	1.68	1.87	2.10
Observables								
Elliptic Flow (kaons)	300	150	80	40	20	40	60	80
Chiral Magnetic Effect	70	60	50	50	50	70	80	100
Directed Flow (protons)	20	30	35	45	50	60	70	90
Femtoscopy (tilt angle)	60	50	40	50	65	70	80	100
Net-Proton Kurtosis	36	50	75	125	200	400	950	NA
Multi-strange baryons	300	100	60	40	25	30	50	100
Hypertritons	200	100	80	50	50	60	70	100
Requested Number of Events	300	100	100	100	100	100	100	100

Projecting 7.7 GeV run time

Collision Energy (GeV)	7.7	9.2	11.5	14.6	17.1	19.6	27
Performance in BES-I	2010	NA	2010				
Good Events (M)	4.3	NA	11.7				
Days running	19	NA	10				
Data Hours per day	11	NA	12				
Fill Length (min)	10	NA	20				
Good Event Rate (Hz)	7	NA	30				
Max DAQ Rate (Hz)	80	NA	140				
Performance in BES-II (**achieved**)	2021	2020	2020	2019	2021	2019	2018
Required Number of Events	100	160	230	300	250	400	NA
Achieved Number of Events	2.9	**162**	**235**	**324**	TBD	**582**	**560**
fill length (min)	20-45	**45**	**25**	**45**	50	**60**	**120**
Good Event Rate (Hz)	16-24	**33**	**80**	**170**	265	**400**	**620**
Max DAQ rate (Hz)	400	**700**	**550**	**800**	1300	**1800**	**2200**
Data Hours per day	12-15	**13**	**13**	**9**	15	**10**	**9**
Projected number of weeks	11-20	8.5-14	7.6-10	5.5	2.5	4.5	NA
weeks to reach goals	TBD	**14.6****	**8.9**	**8.6***	TBD	**5.1***	**4.0**

Run-20b 7.7 GeV running over holiday weekend reached a good event rate average of 16 Hz and up to 16 hours/day of data taking!!

Below injection energy luminosity scales well with γ^3

Rescaled running times in agreement with lower-middle end of projections

7.7 GeV projections 11-20 (~28-CAD) weeks optimistic/pessimistic assumptions

*Running with significant LEReC

**Run-20b running

Executive summary II:

Second highest priority Run-21:

Au+Au $\sqrt{s_{NN}}$ = 3 GeV (FXT) 300 M minbias 3 days

- Net proton fluctuations, GCE vs GC, light hypernuclei production

Au+Au $\sqrt{s_{NN}}$ = 9.2, 11.5, 13.7 GeV (FXT) 50 M minbias 3 days

- Enhanced understanding of baryon stopping

Third highest priority Run-21:

O+O $\sqrt{s_{NN}}$ = 200 GeV 400(200) M minbias(central) 1 week

- Enhanced understanding of early conditions in small systems

Au+Au $\sqrt{s_{NN}}$ = 17.1 GeV 250 M minbias 2.5 weeks

- Probe for CP via non-monotonic behavior of higher order moments

Au+Au $\sqrt{s_{NN}}$ = 3 GeV (FXT) 2 B minbias 3 weeks

Higher order (>4) moments, ϕ flow, double-Λ hypernuclei

Citation rate/paper continues linear rise

Citesummary excluding self-citations or RPP citations

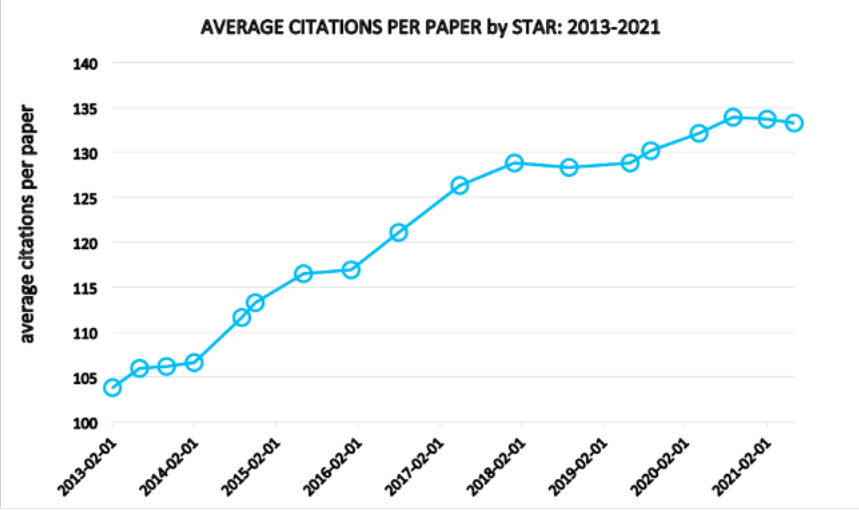
Generated on 2021-06-17

262 papers found, 262 of them citeable (published or arXiv)

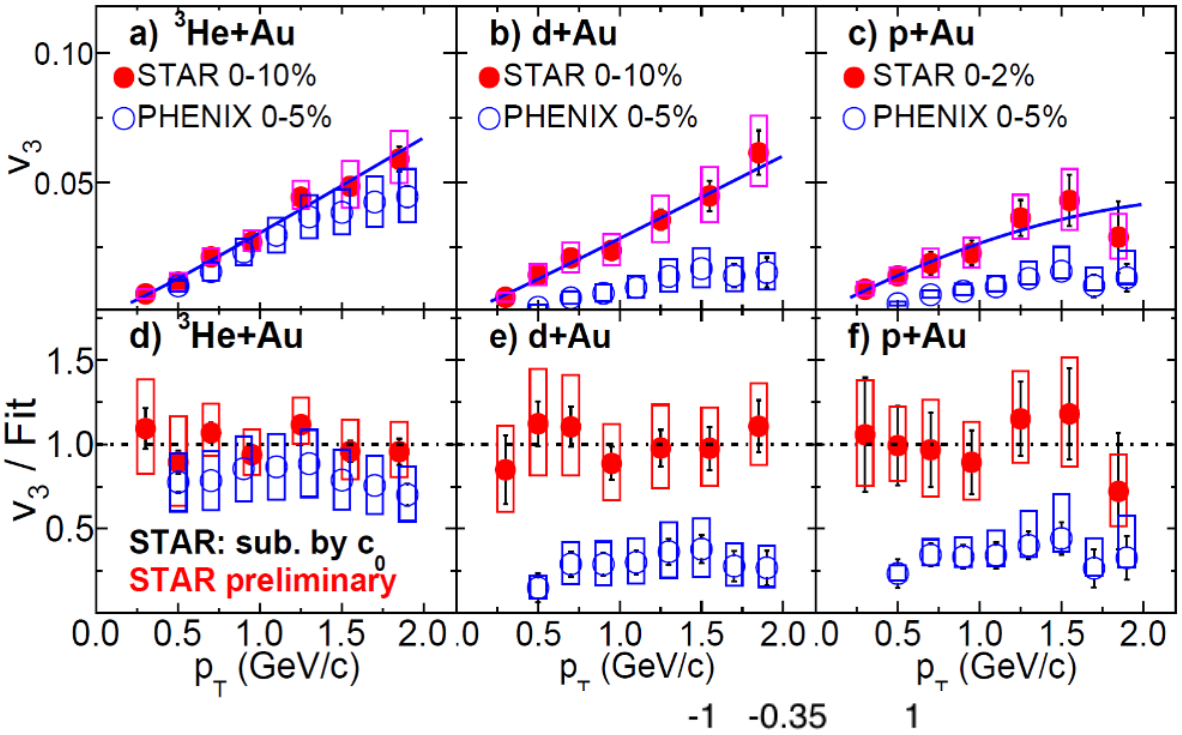
Citation summary results	Citeable papers	Citeable papers excluding self cites
Total number of papers analyzed:	262	262
Total number of citations:	34,934	23,947
Average citations per paper:	133.3	91.4
Breakdown of papers by citations:		
Renowned papers (500+)	11	7
Famous papers (250-499)	24	15
Very well-known papers (100-249)	59	37
Well-known papers (50-99)	59	58
Known papers (10-49)	84	101
Less known papers (1-9)	22	41
Unknown papers (0)	3	3
h_{HEP} index [?]	96	78

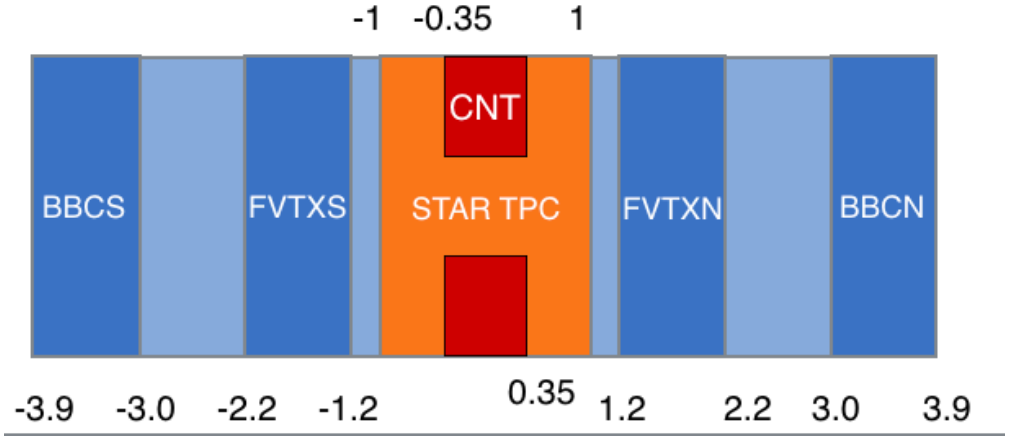
Citations (as per Jun. 17th, 2021)

- 34,934 citations
- 262 peer-reviewed scientific papers
- 2005 white paper: 3324
- average citations/paper: 133.3



Time for one more run!





Triangular flow v_3 in d+Au and p+Au differs by a factor of ~3 between STAR and PHENIX.